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THESIS

ATTENTIONAL DRIFT: AN EXPLORATORY STUDY INTO THE DEVELOPMENT OF AN ATTENTION LEVEL MONITORING SYSTEM BASED ON HUMAN EYE FIXATION

by

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March 2010

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13. ABSTRACT (maximum 200 words)

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ATTENTIONAL DRIFT: AN EXPLORATORY STUDY ON THE DEVELOPMENT OF AN ATTENTION MONITORING SYSTEM BASED ON HUMAN EYE FIXATION

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This study was designed to determine if future research into the development of an attention monitoring device based on eye fixation duration is both feasible and warranted. Attentional Drift is an insidious form of distraction where primary task attention is slowly eroded by secondary tasking. It can occur in either very low or very high cognitive demand situations. Recent studies have shown eye fixation duration and glance duration measures have close correlations to attentional demand in visual tasks. In this study, participants completed two 20-minute driving periods in a STISIMtm based simulator wearing a head-mounted eye-tracking system. Eye fixation measures recorded in a single-task low mental demand test did not show a significant increase in eye fixation duration over time in all participants. A second test incorporating secondary task through varied types of conversation did show that eye fixation duration values were affected by thee added cognitive workload. Eye fixation measures showed statistically significant changes in duration as direct result of varying secondary cognitive demand. It is concluded that further experimentation incorporating eye blink-rate factors, utilization of a fixed-base eye-tracking system with a gaze dwell time function and significantly lengthened test runs is both feasible and warranted.

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For my best friend, Matt, who died driving home late one evening, after a long exhausting day, simply missing a curve he had negotiated a thousand times before. It is through his unfortunate death that he inspired me to move forward in this research that has the potential to save many others from a similar fate.

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I. INTRODUCTION

Attentional Drift is a term coined to describe a subtle and insidious form of distraction that occurs when a secondary mental task decreases an individual’s cognitive and perceptual capacity to the detriment of a primary mental task (Burts, Martins, Quimby, & Shattuck, 1998). When a secondary task’s cognitive or perceptual demand results in an attentional shift to the extent that the successful execution of the primary task is no longer probable, we say that Attentional Drift has occurred. Unlike common distractions, such as a loud noise or momentary glance at a vehicle parked on the side of the road, Attentional Drift is a slow process of distraction. Attentional Drift is often undetectable until such time as an attentional cue with sufficient strength recaptures the individual’s attention, returning his or her mental and visual focus to the primary task, or a significant failure of the primary task occurs.

Attentional Drift, as we have defined it, can occur either in situations requiring very high or very low mental workload. The degree of automaticity of a given task influences how susceptible a person is to Attentional Drift. The more automated the behavior, the less cognitive and perceptional demand the execution of the task requires. Automaticity increases through practice, which results in increased efficiencies in learned motor control, perception strategies and procedural coordination (Kahneman, 1973). As automaticity increases, the required cognitive and perceptual effort in turn decreases, freeing up capacity for use on secondary tasks, which may lead to a detrimental level of distraction from the primary task. As workload requirements increase beyond the capacity of an individual, performance begins to decline (Wickens, 2002). This explains why performance that is influenced by Attentional Drift appears to parallel the Yerkes-Dodson performance curve (Yerkes-Dodson, 1908).

Drivers traveling familiar routes or driving within a stabilized environment, such as an open highway, become susceptible to extraneous thoughts that tend to bring mental workload up to a more moderate level. As thoughts cascade from one thought to another, a driver, sensing little or no change in the driving environment, continues to shift their attention deeper and deeper into self-generated (endogenous) cognitive thought. On daily commutes, we often engage in non-associated mental tasking, such as anticipating daily work-related events on the morning commute or sensory stimuli like a song on the radio may trigger memories or remind us of other things not associated with the primary task. Low mental workload demands as a result of high automaticity lead to a degradation in vigilance over time. Drivers can become lulled into a false sense of sensory or perceptual security based on a static set of environmental conditions and a growing degree of confidence in their ability to adequately respond to any potential change in that condition. As that security and confidence grows, drivers may allow themselves to increase their attention on a secondary mental task. If you have ever looked down at the odometer on a long drive and were surprised by the distance you've traveled, then, in a panic shifted your gaze to the gas gauge, you've experienced Attentional Drift as a result of low mental demand.

Attentional Drift works differently in higher mental workload situations as a result of an increasing external demand rather than a self-generated cognitive demand as was discussed in the first case. In the high workload case, attentional demands that reduce primary task performance may come from secondary tasking closely associated with a primary task but require attentional demands that exceed the capacity of the individual.

Cellular telephone use while driving is as an excellent example of how drivers become slowly engrossed in secondary task behavior through conversation to the point at which they begin to miss key cues, which in turn reduces performance. Numerous studies have shown that cellular telephone use while driving results in significantly reduced performance (Strayer & Drews, 1999; Strayer & Johnston, 2001; Harbluk & Noy, 2002; Recarte & Nunes, 2002, 2003). On a daily basis, we see drivers engaged on the phone drifting within their lanes, attempting lane switches into occupied lanes, and jamming on their brakes as they realize traffic has unexpectedly slowed.

Understanding when and why we permit secondary tasking to draw too much attentional focus away from a primary task is the long-term research goal of this experiment. In order to isolate the point at which sufficient sensory and perceptive attention has shifted to result in a performance detriment, we need to find a physiological indicator of Attentional Drift.

II. LITERATURE REVIEW

A. JUSTIFYING THE STUDY OF ATTENTIONAL DRIFT

Drivers engaged in multitasking activities, such as using a cell phone, eating, drinking, lighting a cigarette, putting on make-up, talking to passengers, and even listening to the radio, suffer significant delays in reaction time, reduction in sensation, perception, and cognition, and overall driving performance (Donmez, Boyle, & Lee, 2006). The delay in reaction time is associated with the limited capacity of human attention (Navon & Gopher, 1979). As drivers' daily commuting times increase, and as new technologies such as Blackberrys, navigation systems, DVDs, etc., become more pervasive, accident rates due to inattention are sure to rise (NHTSA, 2007).

The type of distraction, cognitive demand, and amount of time required to complete a secondary task not associated with driving, affects the potential for a driver to miss a key attentional cue (Navon & Gopher, 1979). When it comes to the operation of vehicles, the earlier the detection of an impending situation, the higher the probability for avoiding error. For that reason, managing distraction or secondary tasks is critical to ensuring primary task success.

Out of 6.3 million U.S. driving accidents in 2005, nearly 4.9 million cases were attributed to driver inattention (Sundeen, 2006). According to a study by the National Highway Transportation Safety Administration and the Virginia Tech Transportation Institute, an estimated 80 percent of crashes and 65 percent of near crashes involved some form of driver inattention (Sundeen, 2007). Approximately 34,000 fatalities and 2.1 million injuries totaling as much as $184 billion in annual economic damage could be at least somewhat mitigated by an embedded device that could monitor driver inattention (Sundeen, 2007). If an adequate physiological measure is discovered, then an alert could be sound when the degree of inattention associated with a known probability of error is exhibited.

B. EXPERIMENTAL DEVELOPMENT

Poor driving performance and increased accident statistics can be readily attributed to cell phone operation while driving (Strayer & Johnson, 2001; Harbluk & Noy, 2002; Recarte & Nunes, 2002; Strayer, Drews & Johnston, 2003; Strayer & Drews, 2004; Zheng, McConkie, & Simons, 2005). As a result of those studies, individual States are enacting laws permitting the use of a cellular phone only in a hands-free mode. The likelihood of getting involved in an automobile accident increases by 38 percent when dialing a cell phone while driving (NHTSA, 2007). Conversation, whether on or off a cellular phone while operating a vehicle, increases the chance of having an accident by 30 percent (NHTSA, 2007). Two studies compared the difference between having a cell phone conversation to having a conversation with a passenger in the vehicle. Despite the notion that an individual present can see the driving situation and adjust their comments accordingly, research suggests there is no significant difference in the likelihood of getting into an accident (Zheng, McConkie, & Simons, 2005). Drivers otherwise engaged on a cell phone will ignore the distracting comments because they are aware of the impending situational danger (Nunes & Recarte, 2002). Research, however, supports the concept that distraction as a result of cell phone secondary tasking is indicative of an overall reduction in attention not just isolated to key periods (Recarte & Nunes, 2003). The results of these studies support the choice to omit the use of a cellular handset during the present study. Secondary-task questioning took the form of a verbal discussion between an adjacent experimenter and the driving participant.

The underlying theoretical basis for this study is based on the Multiple Resource Theory (MRT) of Human Cognitive Performance (Wickens, 2002). MRT pertains to our ability to effectively perform multiple tasks simultaneously on a cognitive level. Divided attention studies concentrate on a subject’s ability to perform two tasks together under various controlled conditions. Wicken’s successive studies since 1984, culminating in the last iteration in 2002, have determined three main factors that affect dual-task performance: task similarity, automaticity (practice), and difficulty. Those successive studies show that as tasks became increasingly similar, mental workload is increased to overcome interference tendencies. As tasks became more difficult, workload is increased.

And conversely, as automaticity of a given task or task set is increased, workload is decreased. Wickens (1984, 1992) provided an alternative explanation for the findings of dual-task studies. He argued that people possess multiple resource pools and proposed that there are three successive stages of processing: encoding, central processing, and responding. All three stages tap an individuals' mental workload capacity. Wickens (1992) also stated that MRT pertains not only to central cognitive processes but to sensory processes and response processes, as well. This is particularly important in understanding the relationship between an increase in cognitive demands and its potential corresponding detrimental effect on sensory processing capacity. As mental workload increases beyond an operator's normal capacity, the ability to handle increased taskloading decreases, resulting in diminished performance capacity.

C. DETERMINING A PHYSIOLOGICAL MEASURE

The Peripheral Detection Task (PDT) test was developed by Horbluk and Noy (2002) to study the effects on visual field size as a result of multi-tasking. In a simulation, key attentional cues are depicted in the periphery while a test subject completes a secondary task while driving. Responses to the peripheral cues are recorded along with performance data from the driving task. Harbluk and Noy (2002) incorporated a PDT test and discovered that humans not only respond to increased visual workload by increasing their scan rate but they also respond by reducing the overall visual field area they scan. This is similar to the findings of Recarte and Nunes (2002) who found minimal reductions in visual field size with light conversation. In moderate conversation requiring small computational tasks, the visual field size was reduced to 92 percent of the normal visual field size. When given extensive secondary tasking, visual field size was reduced to 87.5 percent. They concluded that human visual field size decreases to offset the additional cognitive demand. A smaller field size requires less sensory capacity to maintain an adequate scan, thereby freeing up more visual resource capacity.

Using PDT techniques, Thomas and Wickens (2001) were able to observe a quantifiable decrease in participant perceivable Field of View (FOV) as mental taskloading was increased towards capacity. Olsson and Burns (2000) demonstrated the validity of the PDT to detect the relationship between higher mental taskload and peripheral vision degradation. The causal factors for the decrease in perceivable field were thought to be two-fold. First, FOV degradation can result from task overloading where it is speculated that the mind sacrifices the peripheral visual data to allow for increased cognitive capacity. And secondly, an individual can become pre-occupied with foveal or centralized visual information sources resulting in inattention to peripheral data. Both situations can occur even without the individual being aware of the effect (Olsson & Burns, 2000). For example, a driver engaged in secondary tasking such as a conversation, phone call, intense memory recall or visualization, might miss essential visual cues to an upcoming situation as a result of the decreased FOV (Olsson & Burns, 2000).

Recarte and Nunes (2000) studied the effects of spatial-imagery tasks on drivers. They discovered that drivers fixated on points longer and, therefore, glanced at their mirrors and dashboard less. Recarte and Nunes (2003) expanded this notion in an effort to try to relate eye scan behavioral changes with varying degrees of mental workload. Eye gaze measures showed a direct relationship to the instances of error. They concluded that mental activity alters the strategies of visual information acquisition while driving. Performance of mental tasks prevents the application of top-down processes, resulting in processing impairment now referred to as “in-attentional blindness.” “Looked but failed to see,” “I saw it too late,” or “I didn’t expect it” are all common statements given after accidents when drivers experience some form of attentional blindness (Recarte & Nunes, 2003).

Donmez, Boyle and Lee (2006) investigated ways to create driver distraction mitigation strategies with in-vehicle devices such as a navigation system cut-offs at certain speeds or when cornering is detected. They found that visual distractions were significantly more distracting than audio distractions when it came to overall driving performance. Visual distractions that force gaze to the vehicle interior were especially distracting resulting in increased lane deviation, more erratic steering, and delayed reaction times. Audio distractions manifested themselves in changes to how smoothly (by measuring variation in the control inputs) a particular action was performed, such as braking or lane changes (Donmez et al., 2006). The Donmez et al. studies were based on the same concepts explored by Recarte and Nunes (2003) where they studied the consequences of verbal and spatial imagery tasks on visual search patterns and fixation durations. They measured pupillary dilation to assess the cognitive workload for each task and found that visual functional field size decreased and when compared with normal driving, eye fixations were longer during the spatial imagery task (Nunes & Recarte, 2000, 2003).

Harbluk and Noy (2002) focused on varying the degrees of complexity within similar cognitive tasks using on-board interactive technologies. The findings of their study were consistent with the explanation that distracting cognitive tasks compete for attentional resources. Measuring saccadic movements, the high-speed ballistic eye-movements that facilitate exploration of the visual field, they found that the mean number of saccades per 5-second interval was significantly lower in the difficult addition condition (6.72) than in the easy addition (7.42) or no task condition (7.53). What is surprising, aside from the fact that the research was conducted during real-world driving, was that, when the tasking became too difficult, driver's became aware of their inability to adequately complete the arithmetic task without serious detriment to the driving task.

Each of the aforementioned studies used techniques that are leveraged in this experiment to study the effect of secondary tasking and its commensurate physiological response. Saccadic eye movement, peripheral detection task (field of view measures), pupillary dilation, and eye fixation measures all react to changes in cognitive load. Those studies enable us to narrow the list of potential physiological measures to those dealing exclusively with the eye. Pupillary dilation is a physiological response to cognitive workload independent of where the eye is looking. But, in a visually based task, it would make sense that the measure would need to be associated with the scanning of the visual environment to have any association with attention. Saccadic measures, PDT-FOV measures and gaze dwell time measures all require calibration with the user's visual field. The object of this study is to find a physiological indicator that permits simulation immersion and does not require individual calibration. This leaves eye fixation duration. Even though the measure computes angular eye movements, it does not require calibration to a visual field or to the user, if a non head-mounted eye-tracker is used. It simply records the amount of time the eye is stationary between movements.

D. EYE FIXATION DURATION AS A PHYSIOLOGICAL MEASURE

An experiment by Van Orden, Limbert, Makeig and Jung (2001) discovered that moving mean estimations of eye fixations using artificial neural network techniques enabled information from multiple eye measures to be combined to produce reliable near-real-time indications of workload in some visuo-spatial tasks. This notion that eye fixations, if suitably regionalized, could be formulated into identifiable patterns provides the basis by which a physiological performance indication tool may be developed based solely on eye activity.

The application of eye fixation measures as a physiological indicator of attentional degradation is predicated upon the assumption that the act of visual scanning of the external environment is critical to the accurate development and maintenance of sufficient situational awareness. The degree to which the eyes are not actively searching the visual field would then relate to a corresponding decrease in the level of attention applied to the search task. From a theoretical point of view, we can apply Wickens' definition of multiple resource theory to attention. For the purpose of the present study, we define attention in the driving task as the application of sufficient sensory and cognitive resources to safely react to changes in the operating environment. Then, in keeping with Wickens and Kahneman's original views, there will exist a capacity limit or limited attentional resources to be spent or allocated to a particular task. As sensory and cognitive tasks increase beyond the capacity of the human to modulate the response by changing scan rate, visual field size, or scan pattern, the amount of attentional resources available are depleted and performance suffers (Kahneman, 1973). If we describe attention within the visual sensory modality to mean the active search, detection, and tracking of pertinent objects within the environment, then the act of actively scanning the external visual environment would constitute visual attention. Therefore, we can conversely conclude that a quantifiable reduction in eye scan behavior could be a reliable indicator of inattention.

E. EXPERIMENTAL SUPPORT FOR USING EYE FIXATION

Several studies conducted in real and simulated environments have shown that there are strong associations between eye glance measures and driving performance (Olsson & Burns, 2000; Recarte & Nunes, 2002; Harbluk & Noy, 2002; Patten, Kircher, Ostlund & Nilsson, 2004). Most of these studies investigated the effects of offset gaze as a result of secondary task demands such as tuning a radio, managing a navigation system, or dialing a cell phone. The data collected clearly showed that, as the number of glances and the total glance duration to in-vehicle devices increases, the number of lane departures increases (Zhang, Smith, & Witt, 2006; Patten et al., 2004).

Zhang et al. (2006) conducted the only study so far to attempt to directly attribute an eye fixation measure to specific driving performance values. They determined that correlation coefficients between several types of eye glance measures and reaction-time performance variables were reliably high. Participants were tested using a driving simulator and were directed to read several different passages on the display screen that varied in length and complexity. Using performance variables, such as lane departure time, lane deviation position, steering entropy, mean glance time, glance frequency and total glance duration, they found that an increased level of visual distraction leads to poorer driving performance and slower reaction times. Reaction time appeared to increase with total glance duration. More specifically, Zhang et al. concluded that, for every 25 percent increase in glance duration, reaction time is increased by 0.39 seconds and 0.06 meters increase standard deviation of lane position. At 65 MPH, those measures equate to 37 additional feet of stopping distance lost and three inches of lane deviation for a four second glance instead of a three second glance.

Experimental research supports the notion that an eye measure may be attributable to detecting Attentional Drift in both low and high workload situations. Van Orden, Makeig, and Jung (2000) determined that eye activity was correlated with decreases in vigilance. A later study determined that visual workload has a direct impact on multiple measures of eye activity to include blink rate and duration, gaze dwell time, saccadic extent, fixation frequency and mean pupillary diameter (Van Orden, Limbert, Makeig, & Jung, 2001). Secondary tasks while driving have been shown to directly affect driver scan patterns and drivers' visual scan rate, and thus, affect the level of situational awareness (Zheng, McConkie, & Simons, 2005).

There are many eye measures to choose from, but which eye measure will be the most effective physiological measure that has the potential to avoid being cumbersome to the operator? By cumbersome, we are referring to not requiring the operator to wear external gear nor require calibration to the user or the visual field. Drivers and pilots cannot be expected to wear external eye-tracking devices while operating in a non-experimental, non-simulator environment. Saccadic extent and gaze dwell time eye measures will require user calibration to the device and to the operable visual field. Newly designed statically mounted eye-tracking devices advertise they can monitor blink duration and number, pupillary diameter, and eye fixation duration. They are measures that will not require user calibration every time, thereby, permitting operational use in the field as well as increased immersion in simulation environments.

Eye fixation duration is the most likely candidate to study as a physiological indicator for changes in attention level. Velichkovsky, Dornhoefer, Pannasch and Unema (2001) postulated the use of eye fixation duration as a potential measure for attentional demand. While studying eye measure behavior as it pertained to pre-attentive and attentive scanning processes, they detected explicit changes to eye fixation duration upon detection of critical events. They stated that there was a noticeable shift in eye behavior when transitioning from a pre-attentive state to an attentive state that is detectable using eye fixation duration as a measure. One of the most promising elements in their conclusion was that, as a critical event occurred, not only was there an associated increase in Cognitive Fixation duration but it was preceded by a preliminary type of fixation and a corresponding increase in the number of longer fixations following the detection.

Velichkovsky et al. (2001) were able to isolate three separate classes of eye fixation behavior and their associated purposes. They classified eye fixation measures as belonging to an Express, Modal or Cognitive Fixation group. Express fixations are associated with pre-scanning and scanning searches of the visual field. Their duration is typically measured in the 150–300 ms range. Modal fixations are associated with determining if a visual target is worthy of a Cognitive Fixation. The Modal Fixation decision is made between 300 ms and 600 ms. The last fixation type is referred to as the Cognitive Fixation, which represents the time actually spent looking at an object and it usually lasts between 600ms and 2 seconds.

The research conducted by Velichkovsky et al. (2001) is highly relevant to the present study. From their work, it can be inferred that eye fixation is a viable means of using eye fixation duration to measure Attentional Drift. Without the ability to differentiate between Express, Modal and Cognitive Fixations, changes to attentional eye behavior would be masked. The trifurcation of the eye fixation means into distinct behavioral classifications enables individual analysis of eye fixation behavioral responses. Without trifurcation of the data, an overall eye fixation mean could wash out any discernable variation in the data set, thereby, eliminating the ability to detect a change in eye fixation behavior. For instance, an increase in the number or duration of Cognitive Fixations as a result of increased cognitive demand might be equally offset by an increase in scan rate to maintain a given level of situational awareness. As scan rate increases, logically, the duration of the Express Fixation measure must decrease in order to accommodate more Express Fixations per unit time. When averaged as a combined group, the increases exhibited in the Cognitive Fixation group may be substantially offset by the increase in the number of shorter duration Express Fixations.

In summary, this experiment is based on the concept that eye fixation duration will change as a result of shifts in cognitive workload. As cognitive workload increases, it requires the increased utilization of an endogenous cognitive visualization system, in turn, there is a corresponding decrease in the capacity for exogenous visualization, principally, external visual scan time. When cognitive visualization demands exceed the ability for increased scan rate and a reduced visual field to compensate for a decrease in available scan time, then the probability for an effective scan to detect critical cues and provide appropriate response feedback diminishes. Performance in the primary visual task then decreases. For this experiment, if we are able to determine that eye fixation duration measures change as a result of varying workload then future research to refine the eye fixation means and determine associated levels of probabilistic degradation to performance is both feasible and warranted.

III. METHOD

We are attempting to determine whether changes in attention during a primary driving task, as a result of varying secondary mental workload, are detectable through the measurement of eye fixation duration. While completing two 20-minute driving periods over the same simulated route, participants will experience one test with no secondary tasking and a second test with varied questions designed to elicit different cognitive visualization workloads. This is a novel approach seeking to determine whether eye fixation duration measures change as a result of time due to reduced vigilance and increased cognitive workload from unassociated thought: daydreaming. It also addresses Attentional Drift as a result of additional secondary task cognitive demand. We conducted one overarching driving experiment incorporating the entire test elements needed to complete five separate data analyses.

The first analysis focuses on determining which of three values of eye fixation duration means account for the most variation as a result of changing workload.

The second analysis studies how eye fixation measures change over time in a simple task as a result of an expected decline in vigilance and commensurate probability for increased endogenous cognitive elaboration.

The third analysis looks at the effects on eye fixation duration due to an increased cognitive workload using conversation and questioning as a secondary task.

The fourth analysis focuses on how eye fixation duration changes in response to the varied types of questions designed to elicit an increased demand for endogenous visualization.

The fifth data analysis focuses on whether or not detectable levels of performance degradation could be attributed to changes in eye fixation duration.

The decision as to whether or not future research regarding the use of the eye-fixation means to detect Attentional Drift is both feasible and warranted will depend on how well eye-fixation duration measures satisfy the aforementioned focus areas within the data analyses.

A. PARTICIPANTS

Thirty people were solicited from the Naval Postgraduate School; California State University, Monterey Bay; and the civilian sector to participate in this study. Although participants were not provided monetary compensation for their assistance, some were compensated through reciprocal experiment participation. Of the 30 participants solicited, only 25 completed testing, due to physical incompatibility issues with the eye-tracking hardware. Eyeglasses, contact lenses, conjunctive tissue scarring, or very dark eye color precluded five individuals from achieving sustained eye measurement data. The participants ranged in age from 24 to 51 years. Five of the 25 participants were female. All participants possessed a valid driver's license and had at least eight years of driving experience.

This experiment did not involve any rigorous activity, but individuals who reported being susceptible to simulator sickness or flicker vertigo were asked not to participate. Additionally, in order to avoid confounding effects from fatigue and nutrition, participants were screened to ensure that proper nutrition and adequate rest were achieved prior to executing the experiment. All participants had a minimum of at least seven hours of sleep and had eaten the previous three meals.

Participants' information pertaining to age, gender, ethnicity, driving experience (years, annual miles, and locale, urban or rural), cell phone usage (how often used and percentage of time used while driving), and susceptibility to simulator sickness were all recorded. All the aforementioned information was used as a screening tool or as potential covariates in data analysis. Prior to execution of the experimental process, all participants were briefed and all signed an IRB form explaining the experiment in detail.

The experiment was a within subject design, with each participant completing the same tasks within the same time constraints. Each participant drove the same 20-minute rural road driving sequence two times. The first sequence utilized driving as the single-task activity. In the second 20-minute sequence, participants driving the same route were given the added secondary task of responding to varying types of questions sequenced across the dual-task driving period. Each set of questions was the same per participant and the same per 5-minute period. All known controllable variables were held constant with the exception of the number of questions per period. Some participants were more adept at answering various types of questions, and the purpose was to maintain a consistent level of mental workload based on the type of questioning throughout each dual-task period. The order of presentation was not counter-balanced. All participants were exposed to the same degree and complexity of questions throughout each particular dual-task period. Each dual-task time period could then be compared to its commensurate period within the single task simulation run. Dependant variables consisted of eye-fixation duration times, eye-fixation relative position, simulator lane deviation, and simulator speed deviation.

B. APPARATUS

1. Driving Simulator

The driving simulator used in this research was a Systems Technology Incorporated STISIM II Drive Simulation System. The simulator is a low fidelity system incorporating a steering wheel with force feedback functionality, as well as brake and accelerator pedals. The program is capable of measuring collision data, speeding behavior, brake reaction time, lane position and deviation, and centerline and road edge crossing. Recordable playback and selectable interactive events such as vehicle passing, pedestrian presence, and traffic with smart vehicle movements, made use of this simulator highly advantageous to this experiment.

2. Computers

A Dell Precision 360$_{tm}$ Pentium 4 computer was used to operate, control, monitor and record eye-tracking data. This computer was sufficient to operate and process eye-tracking data. Computer performance characteristics had no effect on the experiment.

An Alienware$_{tm}$ customized dual-Pentium 4 computer with dual video card outputs was used to run the STISIM II$_{tm}$ driving simulator software. Fidelity of the simulation was dependent on the quality of the video processors. The Alienware$_{tm}$

system video capacity far exceeded the requirements for the simulation program. The utilization of a customized computer provided no enhancement of the standard STISIM II $_{tm}$ display.

Figure 1. Participant Field of View

3. Monitors

The Simulation was displayed on a 50-inch Phillips flat screen TV/monitor. The monitor was centered 44 inches in front of the participant. The visual display of the simulation was 44 inches wide, creating a horizontal visual field of view of 60 degrees. An additional 17-inch monitor was installed to the right and in a lower position out of the participant's normal visual field to assist in setup for the eye-tracking system. Each computer was setup on its own cart, 3 feet to the participant's right side in a perpendicular fashion to enable the experimenter a full simultaneous view of both monitors and the participant during the experiment. The experimenter was positioned at about 90 degrees to the participant, which precluded face-to-face contact.

Figure 2. Observer View

4. Eye Tracker

The ASL-5000 Applied Science Laboratories Model 5000 Eye-tracking system was used along with its accompanying software, listed below.

Figure 3. Eye-tracker Set-up

5. Software

Eye-Tracker: GazeTracker$_{tm}$ software version 04.09.27 was used in conjunction with eye tracking hardware. This version of the eye tracking software included a new feature called Gazetrail$_{tm,}$ which enables the experimenter to see a snake-like trail of a preset number of eye-fixation points. The eye-tracking data was processed using the Eye-analysis software version 5.74.

Data processing: Data processing was accomplished via Microsoft Excel$_{tm}$ and SPSS version 16.

C. PROCEDURE

Participants took approximately one hour to complete the entire experiment. Ten minutes were expended for the initial interview, safety briefing, and control questions, which were administered to ensure that participants understood how the questions and visuo-spatial exercises were to be completed in the second simulation run. Following the initial briefing, five minutes were allocated for the setup of the head mounted eye-tracker and familiarization period with the simulator driving controls. Once the participant was comfortable and all data collection sources were confirmed operational, the first 20-minute driving sequence was initiated. At the end of the first period, there was a 3-minute break while the computer was reinitialized for the second, higher workload 20-minute driving period. During this period, participants were permitted to ask questions and comment on the simulator. However, they were not allowed to stand or move about the lab. The casual questioning period, which accounted for the first five minutes of the second simulation run, enabled the participants to ask questions about the study and how it was to progress over the remaining fifteen minutes. Up until that point, participants had been told to set aside at least two hours for the experiment. The expectation of a longer experiment was purposely incorporated to get participants to relax in anticipation of a long slow country drive rather than focusing on maximizing their driving score. An anxious or competitive driver would more than likely influence data collection with heightened scan rates and an intentional level of increased vigilance. At the end of the hour, participants were given the Pensacola Simulator Sickness Survey. They were then debriefed on the complete purpose of each section of the study, aside from measuring eye fixation and their responses to varying question levels.

Table 1. Experiment Timeline

Time (Minutes)	*Scheduled Experimental Task*
10	1. In-brief, Demographics Collection, IRB, and Control Questioning
5	2. Eye-tracker Set-up, Calibration, and Simulator Familiarization
20	3. Commence Single-task Simulated Driving Run
3	4. Re-initialize Computer, Check Eye-tracker Calibration
20	5. Commence Dual-task Simulated Driving Run
2	6. Debrief Study, Complete Pensacola Simulator Sickness Evaluation

The room was set in half lighting to begin the dark adaptation process. Individual demographic and cell phone use data were collected. Once the IRB paperwork was complete, participants were presented with a poster on which there were several pictures and they were asked to memorize the location of the pictures. Once memorized, the participants were asked to turn the poster over. A sample questioning phase then started with three mathematical computations (double-digit multiplication), a difficult memory recall question involving the name of their second grade schoolteacher, and lastly, three questions asking them to recall the names and locations of various pictures depicted on the poster. This questioning period was designed to ensure that participants understood how the questioning process worked to preclude any disruption of the simulation due to confusion. The last test that the participants practiced before moving to the simulator was a visuo-spatial activity involving the determination of the symmetrical axis on which alphabet letters could be rotated. Participants were then given another poster to review for visuo-spatial recollection in the fourth period of the dual-task simulation run. The participants were then intentionally briefed on the single-task simulator scenario as if it were a long extended country drive. The briefing emphasized safety and comfort, and stressed the importance of maintaining a driving speed of 65 mph.

The first and second 20-minute drive sequences were identical. The STISIM II_{tm} software was programmed to provide a standardized set of curves in the roadway within each 5-minute sequence. Each 5-minute sequence contained the same number and mix of curve lengths in differing orders randomized with respect to the direction. Each 5-minute period also contained at least two dynamic events such as opposing traffic or the occasional passing vehicle. Each segment had one 65 mph speed sign as a reminder to maintain speed.

Eye-tracking data, speed and lane deviation scores were recorded for both of the 20-minute segments. There was no familiarization period. Participants could ask questions during the first minute. The software simulation was basic in nature; there were no stops, no intersections, and no braking required. Drivers were told to stay in the lane and drive at 65 mph. If participants continued to talk past the first minutes in the first segment they were asked to stop talking; further talking was disregarded. The first simulation run (single-task) was designed to elicit endogenous distraction and external conversation would defeat the objective. During the second 20-minute simulation (dual-task), participants were allowed to talk and ask questions because the second simulation run was dedicated to exogenous distraction.

The second driving simulation sequence concentrated on measuring eye fixation duration time in response to an increased cognitive workload. The secondary task demands were created through the use of continuous questioning. The second simulation run was also equally divided into four 5-minute periods. The first 5-minute time period consisted of open conversation with a list of questions on topics such as work, children, movies, and what they thought of the experiment and the simulation quality. The second period concentrated on memory recall questions. Obscure personal questions such as their mother's middle name, the name of various grade school teachers, and then a standard set of Trivial Pursuit game questions were asked until the period ran out. The third period's questioning was based on mathematical and calendar computations. Several sets of two-digit multiplication and three-digit addition questions were directed at participants. Additionally, calendar-based computations similar to everyday event planning and scheduling were requested. The final period utilized the recall of the poster picture arrangements, the execution of the alphabet symmetrical axis determination task and, if time remained, the participants were asked to provide detailed visual descriptions of key people and events in their lives. The object of the fourth period questioning was to force the participant to rely on internal cognitive visual constructs to answer the questions.

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IV. RESULTS

Twenty participants completed the experiment in its entirety. Of the 25 participants who completed both driving simulation runs, five participants' data sets were unusable due to large sections of missing data. Data collection segments missing more than two minutes were determined to be unusable.

Eye fixation data was extracted from the Eye-anal$_{tm}$ analysis software associated with the ASL-5000 Eye-Tracking System. Each of a participant's two 20-minute simulation runs produced a time-linked set of eye tracking data averaging roughly 2000 data points each. The data sets in the first simulation run were grouped into 5-minute intervals to correlate with the question periods executed during the second simulation run. The data were then separated into the three types of fixations in accordance with Velichkovsky's eye fixation classification (Velichkovsky, 2000). The three groups were: a 100–300 ms group (Express Fixations), a 301–600 ms group (Modal Fixations), and the greater than 600 ms group (Cognitive Fixations).

The mean duration for each of the three eye fixation classes was computed for during each 5-minute time period on both simulation runs. A fourth measure, the Cognitive Count, is a tabulation of the number of Cognitive Fixations for a respective 5-minute period. The Cognitive Count is the numeric representation of the fixations over 600ms for a given period. The Cognitive Count will show increases and decreases in the number of Cognitive Fixations as a result of time or mental workload in addition to the Cognitive Fixation mean data. Analysis of the change in Cognitive Count with respect to mean Cognitive Fixation time may determine if there is an inverse relationship between them. The Appendix contains the full data set associated with all 20 participants with usable eye fixation data.

Table 2 represents the data associated with the first 5 participants of the 20 total participants.

Table 2. Consolidated Data Listing of Computed Fixation Means

Participant	Trial Run	Time Block	Question	Express Mean (ms)	Modal Mean (ms)	Cognitive Mean (ms)	Cognitive Count
4	1	1		168	400	817	1
4	1	2		157	368	617	2
4	1	3		155	392	820	8
4	1	4		153	398	884	8
4	2	1	Casual	171	396	827	34
4	2	2	Recall	165	378	714	5
4	2	3	Computation	171	412	756	3
4	2	4	Visuo-spatial	148	377	817	1
5	1	1		186	410	1052	101
5	1	2		191	412	1036	115
5	1	3		202	405	1030	119
5	1	4		186	406	1138	57
5	2	1	Casual	178	401	884	37
5	2	2	Recall	175	402	831	40
5	2	3	Computation	169	401	797	29
5	2	4	Visuo-spatial	172	408	780	56
6	1	1		182	435	1267	75
6	1	2		186	437	1166	146
6	1	3		201	403	1275	95
6	1	4		188	392	1356	88
6	2	1	Casual	183	418	1236	152
6	2	2	Recall	176	427	1240	130
6	2	3	Computation	170	423	1328	128
6	2	4	Visuo-spatial	161	401	1474	63
7	1	1		203	425	1246	151
7	1	2		201	431	1198	153
7	1	3		206	414	1236	138
7	1	4		198	421	1123	150
7	2	1	Casual	175	417	1180	140
7	2	2	Recall	176	428	1260	116
7	2	3	Computation	176	419	1339	102
7	2	4	Visuo-spatial	178	423	1444	86
8	1	1		203	433	1290	153
8	1	2		186	420	1142	157
8	1	3		194	422	1475	127
8	1	4		180	425	1344	138
8	2	1	Casual	179	429	1038	119
8	2	2	Recall	180	404	901	104
8	2	3	Computation	201	435	1164	133
8	2	4	Visuo-spatial	189	434	1047	141

A. EYE FIXATION CLASSIFICATION

On visual inspection of Table A1 (see Appendix), participants' Express Fixation durations maintained roughly the same means throughout both runs. A paired t-test, however, showed that a statistically significant overall shift in Express Fixation duration occurred between simulation run 1 and simulation run 2 with $t(19) = 2.818$ and $p<.011$. Modal Fixation means exhibited only negligible changes over time within each trial run and between trial runs. A paired t-test showed no statistical difference occurred between simulation run 1 and simulation run two with $t(19) = 0.999$; $p<.330$. Cognitive Fixation means, however, exhibited the greatest amount of change over the course of a participant's two trial runs. A paired t-test on the shift in Cognitive fixation duration showed that a statistically significant overall shift in means occurred between simulation run 1 and simulation run 2 with $t(19) = 3.910$; $p<.001$. As a result of the first analysis, we will focus the rest of the results section on the study of the Cognitive Fixation duration.

B. SIMULATION RUN ONE: SINGLE-TASK TRIAL RESULTS

Figure 4 is a plot of the combined Cognitive Fixation means for all participants across the single-task simulation period. The box plot was divided into 5-minute time blocks corresponding to the experimental time periods.

Single Task Country Drive

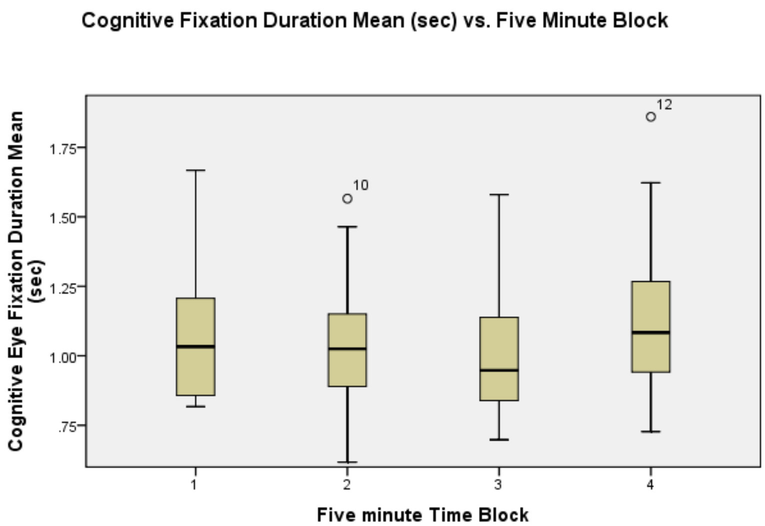

Figure 4. Cognitive Fixation Mean Over Time

A general description of the change in Cognitive Fixation means over time shows that, in the beginning on Figure 4, the first two blocks have roughly the same mean but the second block has a lower overall set of outliers. As time progresses we see that the next time block shows a slight decrease in its mean. The final time block shows a visible increase in the mean in relation to the previous time blocks. It is important to emphasize that the individual boxplots overlap and, thereby, do not represent a significant difference from one period to another as time progresses. We are looking to see if there is a discernable pattern over time within the individual participants. Referring to the full set of raw data (Appendix, Table A1) seventeen of the twenty participants' mean Cognitive Fixation duration (i.e., 85 percent) increased from the third time block to the fourth time block. However, a paired t-test between the Cognitive Fixation values in the first block and that of the fourth block showed to be not quite statistically significant with $t(19)= 1.805$; $p<.088$.

The ANOVA in Table 4 shows a significant effect $F(1,19) = 12.331$ and $p < .002$ with regards to an increase in Cognitive Fixation duration over time. The Cognitive Fixation duration over time is represented by a quadratic increasing trend as time progresses.

- **Single-Task ANOVA Statistical Data**

Table 3. Descriptive Statistics of Single-task Cognitive Fixation Means per Period

Period	Mean	Std. Deviation	N
First	1.072490	.2203193	20
Second	1.052200	.2370402	20
Third	1.078475	.4406188	20
Fourth	1.175810	.4581734	20

Table 4. Within-subjects Contrasts for Single-task Cognitive Fixation Means

Source	Factor 1	Type III Sum of Squares	df	Mean Square	F	Sig.
Factor 1	Linear	.113	1	.113	1.894	.185
	Quadratic	.069	1	.069	12.331	.002
	Cubic	.001	1	.001	.017	.896
		1.134	19	.060		
		.107	19	.006		
		.652	19	.034		

C. SIMULATION RUN TWO: DUAL-TASK TRIAL RESULTS

Figure 5 shows the mean Cognitive Fixation duration time per 5-minute time block for all participants. The 5-minute periods correspond to the types of questions posed during that period. During those periods, participants answered only questions related to that specific question type. Sufficient question banks were generated for each period to ensure that participants could not answer all questions available. Each participant was asked the same questions in the same order.

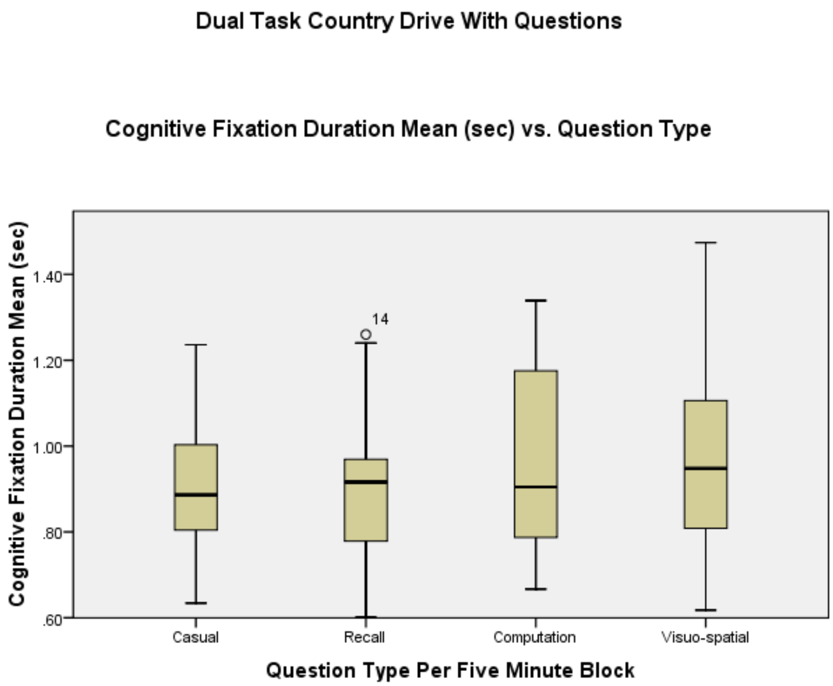

Figure 5. Cognitive Fixation Mean With Respect to Question Type

Figure 5 shows that there is no significant affect by question type on Cognitive Fixation duration across each of the question types relative to each 5-minute period. In order to determine if the means were statistically significant, an ANOVA was completed on the data.

- **Dual-Task ANOVA Statistical Data**

Table 5. Descriptive Statistics of Dual-task Cognitive Fixation Means per Period

Period	Mean	Std. Deviation	N
Casual	.900540	.1565709	20
Recall	.908345	.1693258	20
Computation	.989520	.2193893	20
Visuo-spatial	.983810	.2197518	20

Table 6. Within-Subjects Contrasts for Dual-task Cognitive Fixation Means

Source	Factor 1	Type III Sum of Squares	df	Mean Square	F	Sig.
Factor 1	Linear	.110	1	.110	11.137	.003
	Quadratic	.001	1	.001	.091	.766
	Cubic	.026	1	.026	2.208	.154
Error	Linear	.187	19	.010		
	Quadratic	.191	19	.010		
	Cubic	.221	19	.012		

Table 5 shows that Casual and Recall types of questioning result in nearly identical means overall in relation to one another. Similarly, Computational and Visuo-spatial question types yielded nearly identical overall means. The ANOVA results from Table 6 show that there exists a significant linear relationship $F(1,19)= 11.137$ and $p<.003$ with respect to increasing question complexity and an increase in Cognitive Fixation duration. The differences between the two question groups are shown to be statistically significant. This means that a sufficient degree of change between the individual Cognitive Fixation mean exists between the two greater groups of questions. Each question set is not completely different than the other in terms of its individual affect on Cognitive Fixation duration. But there is an increasing linear relationship to the Cognitive Fixation duration with the increase in question complexity when the questions sets are grouped. The individual question blocks were chosen specifically in an anticipated order of increasing internal mental cognitive visual demand.

D. COMPARING SINGLE-TASK AND DUAL-TASK EFFECTS

The data in Table 5 shows differences in means between two sets of the different types of question modes. Each of the means depicted in Figure 5 is lower than any of the respective block means depicted in Figure 4. Figure 4 and Figure 5 were combined into Figure 6 to illustrate the comparison between the two data sets. Figure 6 clearly shows that the Cognitive Fixation mean in each 5-minute time block during the dual-task simulation run were lower in comparison to the corresponding time block in the single-task simulation. Using the participants' overall mean Cognitive Fixation duration means from both simulations runs depicted in Table 6, a paired t-test t(19) = 3.910 and p<.001 shows a statistically significant difference in Cognitive Fixation duration between the single-task and dual-task simulation runs.

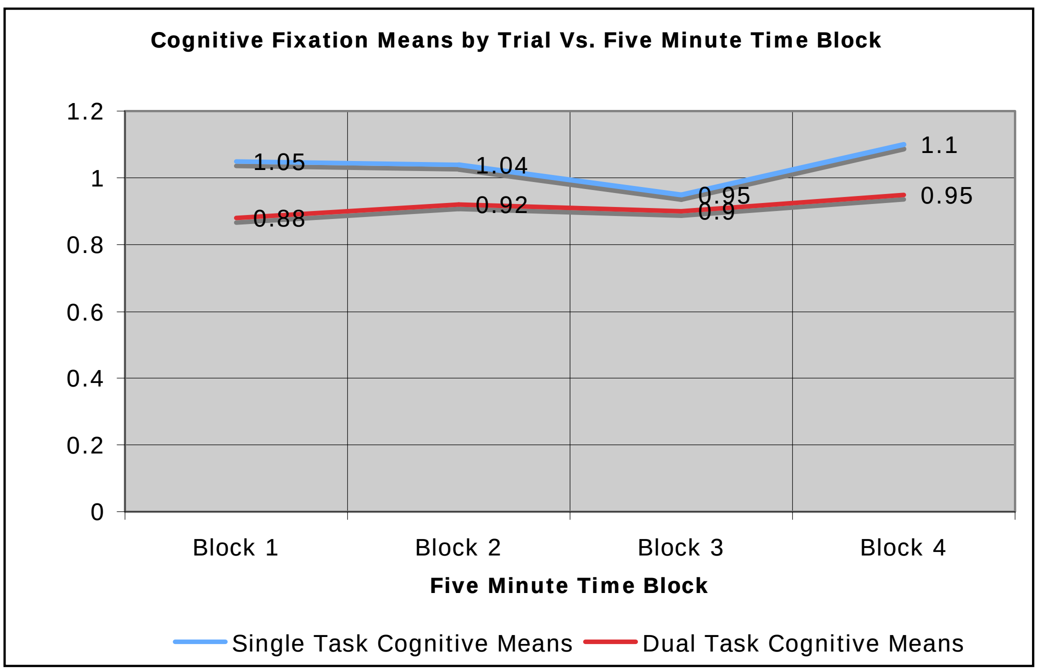

Figure 6. Comparison of Cognitive Means by Trial Over Time

Cognitive Fixation means did not increase with the addition of cognitive mental workload imposed by adding questions to the same time period across Block 1 to Block 4. Contrary to expectation, all Cognitive Fixation means in the dual-task simulation were less than the mean duration in comparison to the Cognitive Fixation mean in its single-task time block counterpart. Questions were not randomized to avoid order effects because it was important to maintain an increasing complexity of the questions over time.

E. DRIVING PERFORMANCE

To assess driving performance, mean speed deviation and mean lane deviation was calculated. In addition, eye fixation duration means were calculated across the entire period as a single 20-minute calculated mean. For each fixation type, the performance measures and associated fixation means are shown in Table 7.

Table 7. Driving Performance Measures and Associated Fixation Means

Participant	Run	Express Mean (ms)	Modal Mean (ms)	Cognitive Mean (ms)	Mean Speed Deviation (mph)	Mean Lane Deviation (feet)
4	1	158	390	785	0.890	1.280
4	2	164	391	778	1.800	1.000
5	1	191	408	1064	1.810	1.160
5	2	174	403	828	3.750	0.853
6	1	189	416	1260	1.010	0.918
6	2	172	417	1319	2.510	0.785
7	1	202	423	1201	1.900	1.085
7	2	176	422	1306	3.540	1.058
8	1	191	425	1313	2.020	1.135
8	2	187	425	1038	2.170	0.788
9	1	191	423	1212	1.490	1.258
9	2	190	427	1117	1.610	1.010
11	1	179	415	1202	1.080	0.795
11	2	179	419	941	1.670	0.618
12	1	193	430	1085	2.090	0.900
12	2	181	425	960	2.530	0.738
14	1	192	424	1130	1.920	1.120
14	2	182	410	905	2.230	0.885
16	1	187	420	869	2.240	0.868
16	2	180	414	794	3.600	1.080
17	1	170	406	918	3.220	1.100
17	2	165	402	748	3.970	0.958
18	1	167	437	764	1.770	0.873
18	2	157	444	708	1.970	0.735
19	1	190	425	957	1.740	0.925
19	2	185	420	971	2.220	0.890
20	1	159	388	819	2.660	0.935
20	2	156	367	755	3.410	0.835
22	1	181	421	1511	4.270	1.205
22	2	181	415	1132	7.210	0.913
23	1	207	417	1056	2.480	0.748
23	2	204	414	953	2.790	0.748
24	1	157	430	908	1.730	1.323
24	2	162	374	727	2.720	1.263
25	1	191	429	966	2.130	0.997
25	2	190	421	1054	2.250	0.685
26	1	204	426	1066	2.220	1.113
26	2	192	418	902	2.790	1.060
27	1	183	416	880	2.180	0.755
27	2	176	406	795	3.500	0.613

The results shown in Table 7 illustrate driving performance differences between the single-task simulation run (run 1) and the dual-task simulation run (run 2). Speed Deviation (in MPH) significantly increased with the additional workload in run 2 with a statistical result $t(19)= 5.324$; $p<.000$. Lane Deviation (in Feet), however, significantly decreased in the second run with a statistical result $t(19)= 4.928$; $p<.000$. Table 7 also shows that participant eye scan rates, indicated by Express Fixation means became shorter as the ability to maintain speed control decreased in the dual-task workload condition. Surprisingly, Cognitive Fixation means decreased in duration, and to a lesser degree, the Express Fixation means decreased as well. The fact that lane deviation decreased in nearly all participants is an unexpected finding.

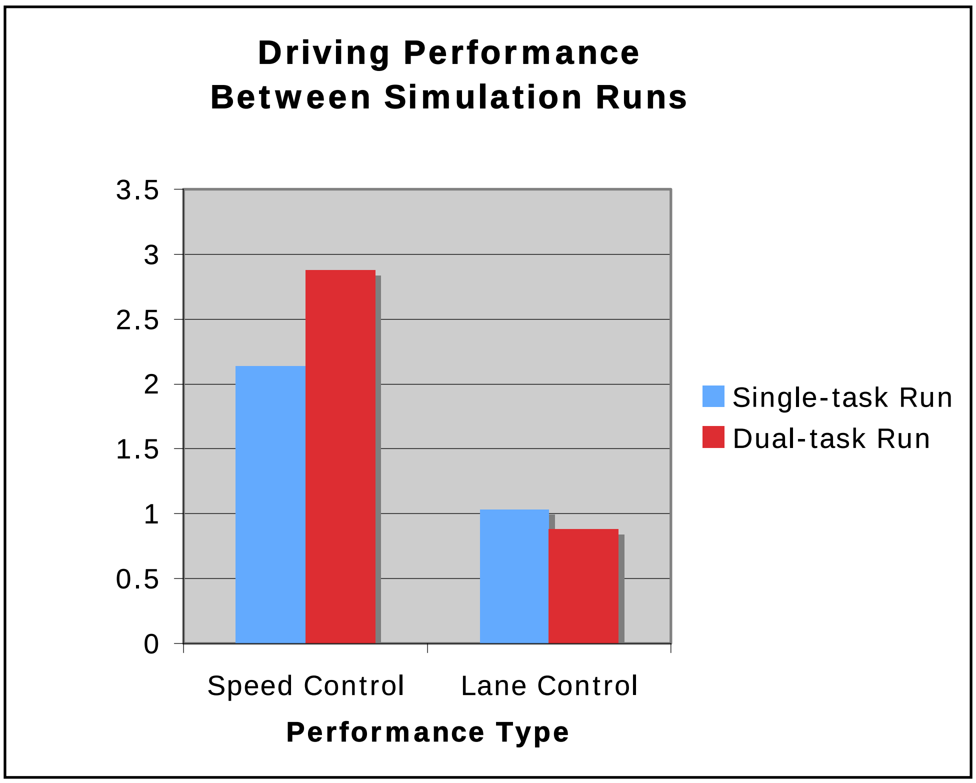

Figure 7. Driving Performance Shift Between Simulation Runs

Figure 7 illustrates how Lane Deviation decreased overall while speed control deviation increased with the increase in cognitive demand through questioning.

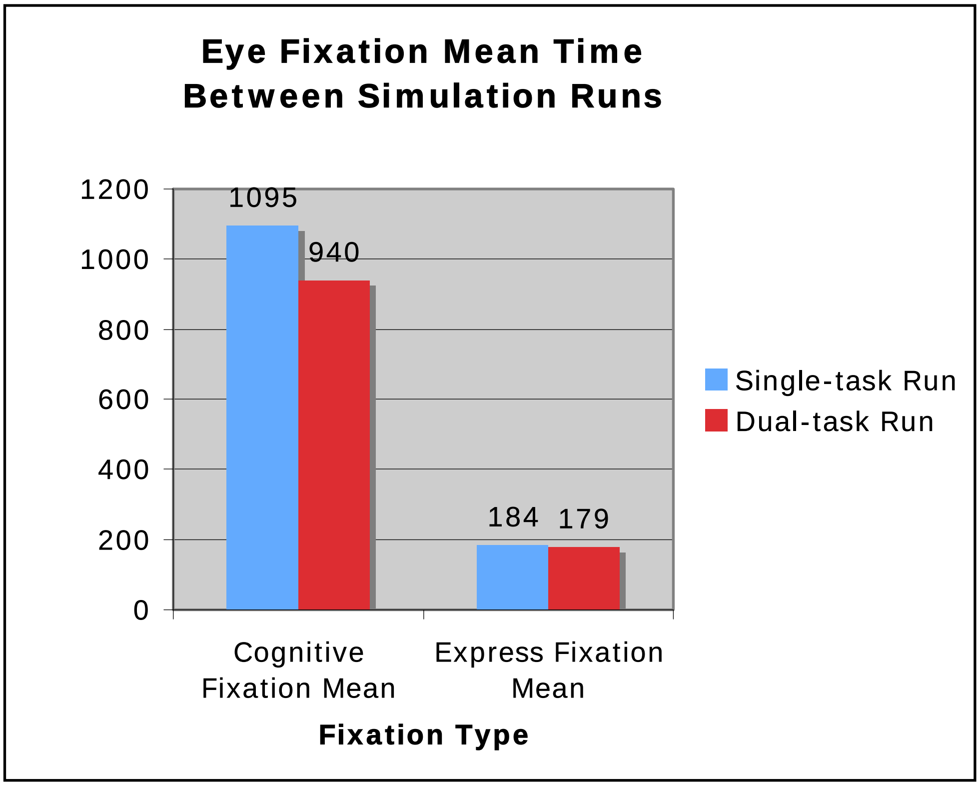

Figure 8. Eye Fixation Mean Time Shift Between Simulation Runs

Figure 8 is a combined chart depicting the combined data from Table 7 and how both Express Fixation mean time and Cognitive Fixation mean time concurrently were shorter in response to the added workload in the second simulation run. The decrease in Cognitive Fixation mean time promulgated by the addition of the secondary mental task-loading was determined to be significant using a paired t-test with a 95 percent confidence interval with a result $t(19)= 3.910$; $p<.001$. The shift in Express Fixation mean time was very small (less than 5 ms). Express fixations as defined by Velichkovsky et al., 2001, are fixations occurring in the 0–300ms time period. In this experiment the recorded spectrum of express fixations occurred solely within the 150–200ms time period. Using a paired t-test with a 95 percent confidence interval, again, yields a statistically significant result $t(19)= 2.134$; $p<.015$.

V. DISCUSSION

The following section covers four topics. The first section focuses on the five assessments, addressing whether or not Cognitive Fixation duration is viable physiological indicator of attention level. A second section provides lessons learned and discusses follow-on considerations for future research. The third section describes how this current thesis effort incorporates several Human Systems Integration (HSI) domains and how the overall results can be further applied to future Naval Research. The final section consists of the formal conclusion.

A. EXPERIMENTAL ANALYSES

The overall goal of this study was to determine if further study is both feasible and warranted in the use of the of Cognitive Fixation duration as a physiological indicator of attentional shift. Validation of the Cognitive Fixation duration will provide a viable measure for not only safety and performance monitoring devices but also enable further research into the causal factors of the Attentional Drift phenomena. With that in mind, the five analyses found not only changes in performance and eye fixation behavior but did so in conjunction with both low and high workload Attentional Drift.

The first data analysis built upon Velichkovsky's (2001) classification schema and focused on determining which value of eye fixation means accounts for the most variation as a result of changing workload. A second data analysis focused on eye fixation mean changes over time in a stable repetitive environment as a result of an expected decline in vigilance, i.e., a low workload Attentional Drift situation. The third analysis looked at the effects on eye fixation duration due to an increased cognitive workload using conversation as a secondary task. This is the simulation representing the high workload Attentional Drift situation. Expanding on the third analysis, the fourth data analysis focused on the sensitivity of the measure in order to determine if it can detect varying degrees of workload initiated by varying the types of question sets posed to participants. The fifth data analysis focused on whether or not detectable levels of performance degradation are attributable to corresponding changes in eye fixation duration.

1. Eye Fixation Classification

Based on Velichkovsky et al. (2001) findings, all fixations greater than 600ms were labeled as a Cognitive Fixation. Finding there were no significant differences between the 300–450ms and 450–600ms Modal Fixation groups, the Modal groups of those subcategories were combined for the current experiment. The Express Fixation group was similarly established to account for all fixations below 300ms. Because the research of Velichkovsky et al. showed a significant relationship between reductions in the number of Express Fixations and increases to Cognitive Fixations at times of critical events, it was decided that these fixation types would become the focus within this experiment.

In an effort to determine which of the three eye fixations types is best suited for use in distinguishing changes as a result of cognitive workload, it is necessary to evaluate each of the individual types of fixations.

There were no differences in Express Fixations means (0–300ms) within each 20-minute run. But when compared between runs, there was a statistically significant decrease in the Express Fixation duration when the secondary task was added. Thus, while Express Fixation duration may be a good indicator for detecting a significant workload shift, it is not useful in detecting differences across a steady-state task period.

The Modal Fixation duration (300–600ms) for each participant remained relatively unchanged throughout each simulation run. There were no statistically significant differences as a result of time or changes in difficulty with secondary task loading. Therefore, Modal Fixation duration does not appear to be a good indicator for measuring shifts in attentional demand.

Cognitive Fixation duration showed the greatest variation across the first simulation run as a result of time and again across the second simulation run as a result of differential question complexity (Table A1 shows that the Cognitive Fixation duration demonstrated the greatest amount variation as a result of changes in mental demand of all three classifications of eye fixation means). Thus, Cognitive Fixation duration was selected as the primary physiological measure to determine change in attentional demand.

Follow-on experimental research should consider refining the eye fixation ranges to further narrow the ranges of the fixation means to ensure that extraneous fixations from data collection are properly assigned or discarded. The multiple bands discovered within the Express Fixation mean should be studied as to why participants fell into two major categories within the same overall Express Fixation range. Is the stratification within the Express Fixation spectrum the result of participant's skill level, comfort state, scan pattern or even environmental factors? And finally, should an eye fixation duration be assessed based on singular fixation durations, a mean of fixations collected over a predetermined fixed time increment, or should it be based on a shift in means collected over a predetermined period? Future studies should use associations with shifts in performance to determine the aforementioned basis for using Cognitive Fixation means as an indicator of a change in attentional demand.

2. Single-task Effects

Previous efforts by Thiffault and Bergeron (2003) have shown that vigilance decreases over time along long monotonous driving scenarios, but they did not use eye fixation measures. Van Orden et al. (2000) used combined eye activity measures such as blink rate, fixation dwell time, and pupillary dilation to show that vigilance in a repetitive task wanes slightly around the 10-minute point. After ten minutes they determined there is an increasingly steady progression in delayed reaction time and error rate until the 20-minute point where vigilance and performance reaches an equilibrium. If Cognitive Fixation duration were to track with an established pattern for decreasing vigilance, then it might be possible to utilize Cognitive Fixation duration as an indicator of potential performance detriment when compared to a probability of error associated with a given duration.

A paired t-test showed that there is no statistical significance between the beginning 5-minute time period and the final period. This result is inconsistent with the interpretation that changes in Cognitive Fixation duration did change with a quadratic increase as expected from the ANOVA. The ANOVA showed there to be a slight quadratic trend increasing over time which substantiates the notion that, as participants initially started with a higher level of task vigilance, the vigilance decreased as denoted by a slight increase in Cognitive Fixation duration. In the final period there was an increasing value for Cognitive Fixation duration. In many participants there was no discernable change in Cognitive Fixation Duration. The lack of change may be due to the fact that at least five of the participants were working especially hard to ensure superior performance "scores" despite the initial attempts to get them to relax. Another source of error may be due to the fact that the 20-minute run would only account for the first half of all the participants experiencing a wane in vigilance. After 20 minutes the other side of the normal curve of participants would show a change. Therefore, Cognitive Fixation duration did not provide a sufficient physiological measure for comparing Attentional Drift in a low vigilance state within this experiment. However, the fact that 13 participants did show an ascending shift in Cognitive Fixation duration lends itself to recommend further experimentation in an improved experiment.

To ensure an improved data collection set, follow-on experimentation must include a dedicated period of time for participant familiarization and the overall simulation run must be longer than 20 minutes in duration. By reducing the number and intensity of roadway curves, in addition to decreasing the density of visual scenery and dynamic events, it will further decrease the attention level required in the execution of the low intensity single-task driving run. Eye fixation duration values can be recorded over one hour, two hour, and even three-hour periods punctuated by ten-minute periods of moderate dynamic simulation activity. The dynamic period can be utilized when performance wanes to a dangerous level or when a substantial reset in attention demand is required to separate trials within a singular run. A substantial increase in simulation run time coupled with individual time period performance measures will be necessary to make a definitive judgment as to whether or not Cognitive Fixation duration is a viable indicator of potential detrimental driving performance.

3. Dual-task Effects

In the dual-task part of this experiment, Cognitive Fixation durations were used to compare the second simulation run (dual-task) to those of the first (single-task) simulation run. As previously mentioned, Strayer et al. (2003) found that different types and increasing levels of secondary mental task loading result in varied performance degradation and are also exhibited physiologically in eye behaviors such as pupillary dilation, increased blink rate and a reduction in field of view. But, will the increase in mental task loading have a corresponding effect on the Cognitive Fixation duration time?

In this instance, we are injecting cognitive tasking that should foster varying degrees of internal mental imaging to answer secondary-task questions successfully. The expectation is that, as questions are posed to the driver-participant, some degree of mental visualization will be required to determine an answer. We speculate that, as the necessity to use more and more of the internal cognitive visualization capacity increases with the complexity of the questions, so too will the duration of the eye's Cognitive Fixation increase as the brain uses the shared components of the cognitive visual system for internal cognition.

The addition of secondary mental task loading had a statistically significant effect on the Cognitive Fixation duration within the second simulation run. Most surprising, is that, in every period during the second simulation run, Cognitive Fixation duration values were less than its corresponding period within the single-task simulation run. This was clearly illustrated in Figure 6. This result was statistically significant for each individual period and as a whole when evaluated across the entire run. The unexpected drop in Cognitive Fixation duration across the entire second run may be directly attributable to an overall increased demand signal that triggers a faster scan rate. A faster scan rate would incorporate shorter fixations to accommodate the increased number of fixations per unit time.

The aforementioned shift in Cognitive Fixation duration seems to be related to a simultaneous decrease in Express Fixation duration. The reduction in the duration of the

Express Fixation means appears to be related to an increase in the scan rate during the second simulation run. Cognitive Fixation hit counts increased so the ratio of time utilized by Cognitive Fixations increased with the added questions. With an increase in the number of the Cognitive Count there is a corresponding decrease in available time for longer Cognitive Fixations. It is quite possible that with the necessity to switch to an increased scan rate (shorter Express Fixations), so too there is a similar reaction to increase the gating rate between internal and external Cognitive Fixations.

Continued research is warranted on the decreasing overall means shift as a result of the secondary taskload. The reduction in Cognitive Fixation duration across all periods when compared to the single-task simulation run was statistically significant. Future research is necessary to determine why the shift is a decreased value rather than an increased value. The research should concentrate on the possibility of eye-blink rate increases as a result of increasing workload as a potential confounding factor. Eye-blinks result in multiple fixations whether or not the eye actually moves during the blink. In order to study the phenomenon better, experiments might focus on varying the degree of workload across a larger spectrum whether it is in the primary or secondary task. By varying the degree of mental workload across a larger spectrum, an experiment could isolate whether or not the change in Cognitive Fixation duration is a gradual response to workload demand (linearly related) or a direct shift in rate as a response to a given level of stimuli when the necessity arises such as in the case of the shift in Express Fixation means.

4. Secondary-task Effects

Rescartes and Nunes (2003) determined that moderate conversation and small computations reduced visual field size by 8 percent. When they increased the complexity of the computations, visual field size was reduced by 12.5 percent. Thomas and Wickens (2001), also using PDT techniques, were able to drive participant field of view even smaller by pushing the mental taskload towards capacity. The peripheral detection task shows changes in FOV with changes in mental workload. The question here is, can the Cognitive Fixation duration be used to in the same manner?

In this part of the experiment, Cognitive Fixation durations were examined to determine if they can be used to differentiate between finer shifts in attentional demand. Secondary-task questioning started out with mild conversational questioning, and then progressed to memory recall questions in the second period to simulate moderate conversation, then in the third period, difficult mathematical computation was next followed by visual-based exercises. By stratifying the different types of questions, we are attempting to determine if varying degrees of question difficulty result in a stratified Cognitive Fixation means across the dual-task simulation run.

By varying the question type for each of the periods in a successively more difficult manner, there should be a commensurate stepped increase in Cognitive Fixation duration with respect to the greater demand for internal cognitive visualization.

An ANOVA completed on the second simulation run showed that the within-subjects the effect of various question types was statistically significant. It also showed a linear increase over time in Cognitive Fixation duration as the questions increased in presumed endogenous visual reliance. The Cognitive Fixation means for the casual and recall question periods were approximately the same at 900ms and 908ms. There was no significant difference between the Computational and Visuospatial tasks, at 923ms and 989ms. When combined, they formulate an overall linear increase in Cognitive Fixation duration. This relationship between conversation and memory recall performance is consistent with the literature. Computational performance characteristics in previous research showed a decline in performance. The addition of the visuo-spatial task questions was novel in this experiment. Although there was no statistical significance between each individual type of questioning, there was a statistical significance between the pairs and they did formulate a linear relationship with respect to complexity.

Thus, Cognitive Fixation duration has demonstrated a degree of sensitivity to discern differing levels of increased cognitive demand. The concept is further supported by the fact that Cognitive Fixation duration responded to an increasing demand for endogenous cognitive elaboration (internal thought or visualization). There appears to be a relationship between varying degrees of cognitive mental taskloading and a commensurate shift in Cognitive Fixation means Cognitive Fixation duration. Further research in this area is both feasible and warranted.

Future experimentation with regards to workload and secondary mental tasking needs to be directly associated with the studies involving performance effects. By varying the performance requirements in addition to varied task-based secondary questioning, the association and degree of sensitivity of the Cognitive Fixation duration can be better studied.

5. Performance Effects

Driver performance is the most critical aspect of this study for determining whether or not the use of Cognitive Fixation duration provides a viable physiological indicator of a shift in attentional demand. Dual-task studies, particularly, driver cell-phone studies, show delayed reaction times in braking, increased lane deviation, and decreased speed control typical with the addition of varying degrees and types of secondary mental task loading (Rantanen & Goldberg, 1999; Donmez, Boyle & Lee, 2006; Nunes & Recarte, 2002; Harbluk & Noy, 2002). In these studies, the performance degradation manifested itself in the driver’s increased reaction time and their inability to maintain a standard level of speed and lane control. Since driver’s reaction times were not tested in this experiment, changes in lane deviation and speed deviation values will provide the only measures of driver performance. Driver performance was measured across the single-task simulation run and then compared to the dual-task simulation run driver performance values. A statistically significant shift in Cognitive Fixation duration resulted from the added secondary mental workload presented in the Dual-task Effects analysis. This result shows a clear reaction to the workload shift indicating that the Cognitive Fixation duration may be a valid physiological indicator of an impending performance degradation.

The performance shifts in this experiment measuring lane deviation and speed deviation provided opposing results. Speed control was shown to worsen with the addition of secondary mental task loading, as expected. But conversely, lane deviation measures unexpectedly improved with the additional mental demand imposed by the questioning in the second simulation run. Figure 7 clearly shows that lane control performance improved with the addition of secondary mental tasking. As evidenced in Figure 8, there was a relative response in the statistically significant decrease in Cognitive Fixation duration. There was also a corresponding increase in the scan rate as evidenced by the decrease in Express Fixation duration. There was a definite performance response in conjunction with a corresponding change in Cognitive Fixation duration but how can the performance improvement with the increased mental demand be explained?

Recarte and Nunes (2002) studied the effects of mental load and loss of speed control in real driving and concluded that the reduction in field of view as a result of the increased mental demand was attributable to the reduction in speed control. A reduction in visual field size with the addition of a secondary mental task is in direct relation to the studies conducted by Thomas and Wickens (2001) and Olsson and Burns (2000) where both their experiments resulted in a quantifiable decrease in perceivable Field of View (FOV) as mental taskloading was increased.

In an effort to determine whether changes in scan or visual field size may be having an effect in this experiment, five participants' were randomly selected and the x-y plots of their eye fixations within the third simulation period from each simulation run were compared. The visual comparisons showed that the number of fixations located in the lower center portion of the field of view where the speedometer was located were either drastically reduced or even completely non-existent. The visual inspection of the x-y plots show that a distinct change in the scan had occurred. Since human beings rely on a phenomenon known as "visual flow" as a means of maintaining a consistent speed while driving, the reduction of peripheral fixations demonstrated to occur in the previously mentioned studies most likely contributed to a decreased perception of speed change (Olsson & Burns, 2000). Peripheral vision is primarily based on black and white contrast changes and is very sensitive to minute change and thus it normally reacts well to dynamic shifts in speed. The reduction in visual field size coupled with the decreased fixations on the speedometer can be logically associated with an increase in speed deviation. An increased fixation volume to the center of the visual field, as a result of a decreasing field of view, may explain the increased performance in maintaining lane position. As a driver, which is going to result in catastrophic failure first, a failure to stay on the road or a failure to maintain speed? It makes sense that the central gaze is increased and the periphery is sacrificed in order to allow for increased cognitive demand.

Secondary mental taskloading had mixed effects on driver performance. Lane deviation decreased, but speed deviation increased. Speed deviation increased significantly as mental task loading increased. Both shifts in performance represented statistically significant changes in performance commensurate with a corresponding statistically significant change in Cognitive Fixation duration. We can, therefore, conclude that there is a direct relationship between changes in performance and a shift in Cognitive Fixation duration. Future research in this subject area is both feasible and warranted.

B. LESSONS LEARNED AND FUTURE CONSIDERATIONS

The most significant trouble experienced throughout this experiment was the inconsistent operation of the eye-tracking device. The inability of the eye-tracker to maintain an adequate corneal reflection in five participants led to their ultimate exclusion from the experiment. Participants with contact lenses, dark iris color, or glasses of small size had to be excluded. Some participants had observable scarring of the conjunctive tissue from sand intrusion on Middle East deployments. The scarring tended to scatter the light beam, making tracking of the eye extremely difficult. Some data collection periods registered only 20 percent of the normal amount of expected fixation measures. Several experimental sessions had to be restarted or rescheduled several times, due to the unreliability of the eye-tracking system.

In order to develop an effective performance monitoring system based on eye measure data, the data must be collectable from all participants. The device needs to be a non-contact system so that it would not be susceptible to adjustment errors or errant slippage. The device must not require constant recalibration between users. Extraneous light sources need to be constrained, such that the device can be used in vehicle simulators that utilize night vision devices in their normal operation. It also must be capable of being hidden from the user such that it is unnoticeable to the extent that immersion in the simulation is not compromised by the overt placement of cameras and other gear. A statically mounted infrared eye-tracking system such as that incorporated in the Face-lab$_{tm}$ and the Smart-eye$_{tm}$ eye-tracking systems would be perfect for the task.

Follow-on research, whether based on eye fixation duration or gaze dwell time, will need to focus on establishing normalized values for the driving population depending on the various speeds and workloads associated with vehicle operation in multiple regimes—traffic, urban and rural environments, inclement weather, etc. Research directed at determining key fixation times associated with increased probabilities for error needs to be established. It could be assumed that certain durations are indicative of a failure to maintain an adequate scan. Shifts in fixation durations over time could be associated with a shift in attention level. The delta between a given set of fixation means could be a result of attentional demand shifts and the self-induced modulation to account for the change in demand.

If Cognitive Fixation duration reacts in response to changes in mental workload and arousal level over time, it makes sense to investigate whether fixation duration also changes as a result of intoxication or fatigue. Drugs, alcohol and fatigue have been shown to have a significant relationship to cognition (Dawson & Reid, 1997). An experimental determination linking the detrimental effects on cognition of scan rate and cognitive elaboration may show that Cognitive Fixation duration can serve to also alert drivers as to their ability to safely drive. The utilization of Cognitive Fixation duration may serve as an overall identifier of potentially degraded performance on a multitude of performance debilitations.

In this experiment, Cognitive Fixation duration provided an initial indication of its ability to respond to changing attentional demands. Because the Cognitive Fixation duration does not require an eye calibration in order to function, it can be easily incorporated as a physiological indicator for use in adaptive computing systems. As mental workload increases beyond capacity, additional workload can be offset by through computer automation shedding repetitive or mundane tasks. The Cognitive Fixation duration may thereby serve as a critical physiological measure used to initiate, monitor and maintain an adaptive computing response.

C. HUMAN SYSTEMS INTEGRATION RESEARCH REQUIREMENT

The completion of this thesis satisfies the final requirement for the master's degree in Human Systems Integration program at the Naval Postgraduate School. Human Systems Integration is a multidisciplinary approach to acquisition strategy devised to improve capability while reducing overall life-cycle cost and developmental schedule.

This research paper is primarily focused on the Human Factors Engineering domain. The long-term research goal is directed at developing a means to study the Attentional Drift phenomenon. Determining whether human performance limitations in vigilance and attention as a result of increased and decreased mental workload are manifested in a quantifiable physiological means is truly a human factors study. Understanding how and why we are unable to prevent ourselves from becoming distracted by secondary tasking at the detriment of primary tasking, especially when the primary tasking is critical to survival, will become an important factor in future system design with respect to operator workload.

The ability to measure and monitor the degree of mental overload and underload would facilitate improved trade-offs between primary and secondary task allocation. The design of a physiologically based system that could monitor mental workload would have far-reaching applications to facilitate the creation of adaptable computer systems capable of dynamically assuming tasks depending on situational demands. For instance, automating aircraft fuel tank balancing while in combat and leaving it up to the pilot in low workload situations is a perfect example of how a mundane task can be managed to both stimulate activity and reduce situational complexity as the situation dictates.

From a Manpower and Personnel standpoint, the ability to monitor and measure performance as a result of mental workload within a given task structure would be invaluable in the determination of the number and types of individuals suited for a task. Once performance standards are determined for a given operation, comparisons based on physiological indication would provide a clearer tool for assessing the true degree of fit for an individual. Along those same lines, training assessment and progress of individual operators can be closely monitored in terms of their ability to accept additional mental task load. Most training programs require operators to undergo subjective training under the tutelage of an experienced operator. From personal experience as a Navy Master Training Specialist and Flight Instructor, it is understood that, in order to assess a student's ability level, workload is either given at a prescribed level and the student is evaluated in his or her ability to adequately perform under that workload, or workload is given in steady increments until the student fails. On failure, the student is assessed at how the failure occurred and, it is hoped, how he or she will avoid the same mistake in the future. This process forces the student to rapidly develop techniques leading to a higher level of automaticity, sometimes without ensuring a fundamental understanding of all the components within the task. The ability to actively monitor attention level within a simulator would enable instructors to detect when students have mastered some operations that have become automatic and enable instruction to concentrate on tasking that the student demonstrates physiological indication of task saturation. Driving a student to failure throughout a training program has ramifications with respect to motivation and confidence. Avoiding the need to drive to training failure and concentrating efforts where best needed would have far reaching benefits in terms of reducing training time, as well as an increased sense of accomplishment, confidence and motivation.

Implementation of a device used to alert operators of a diminished capacity due to inattention or a lack of perceivable vigilance clearly supports both the Systems Safety and Survivability domain requirements and is the main directional focus of this study. An alert generated when an eye-tracking system detects a pre-determined delay in active eye scan, whether based on eye fixation duration or gaze dwell time, would provide operators sufficient warning with an auditory offset to capture or redirect attention back to the primary task in order to prevent operator distraction from exceeding a safe level.

D. CONCLUSION

In response to the overarching experimental goal, the utilization of the Cognitive Fixation duration as a viable physiological indicator of change in attentional demand warrants future research. Experimental data shows that changes in performance as a result of varying mental workload are reflected in associated changes in Cognitive Fixation duration. Follow-on research needs to focus on the development and refinement of a process for calculating an individual's baseline, as well as a determination of what degree of relative shifts in Cognitive Fixation duration is associated with a probability for detrimental performance. Therefore, determining probabilities for performance failure with respect to specific changes in Cognitive Fixation duration would then become a crucial aspect of future research. In order to add increased rigor to the supporting data set, future studies in the utilization of Cognitive Fixation duration should substantially increase both the experimental duration and expand the degree of varied secondary mental workload. Additional performance measures should also be added to investigate the potential for greater instances of error; such as reaction time and response to dynamic events.

This experiment is a step forward in a new direction for performance monitoring. The Cognitive Fixation mean is a measure independent from the need for calibration prior to each execution of an eye-tracking device because it is based on duration and not location. The ability to monitor changes in attentional demand through changes in cognitive eye fixation means provides a basis for not only creating safety devices that can be incorporated into vehicle systems to detect potential degradation to performance, but also into training systems to monitor student overload or underload as a result of attentional demand while learning. Adaptive computing systems will also benefit, since the measure can be easily adapted for monitoring when affixed to a human-computer interface.

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APPENDIX

Table A1. Data Listing of Computed Fixation Means

Participant	Trial Run	Time Block	Question	Express Mean (ms)	Modal Mean (ms)	Cognitive Mean (ms)	Cognitive Count
4	1	1		168	400	817	1
4	1	2		157	368	617	2
4	1	3		155	392	820	8
4	1	4		153	398	884	8
4	2	1	Casual	171	396	827	34
4	2	2	Recall	165	378	714	5
4	2	3	Computation	171	412	756	3
4	2	4	Visuo-spatial	148	377	817	1
5	1	1		186	410	1052	101
5	1	2		191	412	1036	115
5	1	3		202	405	1030	119
5	1	4		186	406	1138	57
5	2	1	Casual	178	401	884	37
5	2	2	Recall	175	402	831	40
5	2	3	Computation	169	401	797	29
5	2	4	Visuo-spatial	172	408	780	56
6	1	1		182	435	1267	75
6	1	2		186	437	1166	146
6	1	3		201	403	1275	95
6	1	4		188	392	1356	88
6	2	1	Casual	183	418	1236	152
6	2	2	Recall	176	427	1240	130
6	2	3	Computation	170	423	1328	128
6	2	4	Visuo-spatial	161	401	1474	63
7	1	1		203	425	1246	151
7	1	2		201	431	1198	153
7	1	3		206	414	1236	138
7	1	4		198	421	1123	150
7	2	1	Casual	175	417	1180	140
7	2	2	Recall	176	428	1260	116
7	2	3	Computation	176	419	1339	102
7	2	4	Visuo-spatial	178	423	1444	86
8	1	1		203	433	1290	153
8	1	2		186	420	1142	157
8	1	3		194	422	1475	127
8	1	4		180	425	1344	138
8	2	1	Casual	179	429	1038	119
8	2	2	Recall	180	404	901	104
8	2	3	Computation	201	435	1164	133
8	2	4	Visuo-spatial	189	434	1047	141

Table A1 cont'd. Data Listing of Computed Fixation Means

Participant	Trial Run	Time Block	Question	Express Mean (ms)	Modal Mean (ms)	Cognitive Mean (ms)	Cognitive Count
9	1	1		191	419	1224	162
9	1	2		188	422	1138	156
9	1	3		192	416	1247	130
9	1	4		194	434	1239	156
9	2	1	Casual	196	434	1009	250
9	2	2	Recall	186	424	1033	158
9	2	3	Computation	203	425	1186	142
9	2	4	Visuospatial	189	425	1239	70
11	1	1		181	431	1079	66
11	1	2		175	411	1392	18
11	1	3		175	410	830	17
11	1	4		184	409	1505	18
11	2	1	Casual	188	422	998	35
11	2	2	Recall	175	415	921	44
11	2	3	Computation	178	423	914	45
11	2	4	Visuospatial	173	415	931	53
12	1	1		190	423	999	155
12	1	2		199	439	1014	152
12	1	3		198	438	1030	144
12	1	4		187	423	1296	102
12	2	1	Casual	184	421	886	120
12	2	2	Recall	176	421	960	132
12	2	3	Computation	186	434	1034	113
12	2	4	Visuospatial	180	424	958	98
14	1	1		192	423	1189	145
14	1	2		197	417	1158	144
14	1	3		194	424	1040	141
14	1	4		186	427	1132	136
14	2	1	Casual	177	409	844	86
14	2	2	Recall	181	405	967	89
14	2	3	Computation	184	409	891	102
14	2	4	Visuospatial	186	417	912	107
16	1	1		183	428	840	48
16	1	2		188	410	842	66
16	1	3		192	432	847	72
16	1	4		185	412	948	79
16	2	1	Casual	192	412	830	65
16	2	2	Recall	187	400	765	51
16	2	3	Computation	187	421	792	55
16	2	4	Visuospatial	192	423	790	56

Table A1 cont'd. Data Listing of Computed Fixation Means

Participant	Trial Run	Time Block	Question	Express Mean (ms)	Modal Mean (ms)	Cognitive Mean (ms)	Cognitive Count
17	1	1		172	393	852	11
17	1	2		166	413	1138	16
17	1	3		170	397	698	7
17	1	4		174	420	986	26
17	2	1	Casual	167	409	732	7
17	2	2	Recall	152	369	726	2
17	2	3	Computation	171	406	767	11
17	2	4	Visuospatial	169	423	768	4
18	1	1		164	419	826	56
18	1	2		166	436	721	28
18	1	3		176	437	773	54
18	1	4		160	457	736	61
18	2	1	Casual	182	465	685	30
18	2	2	Recall	179	433	912	30
18	2	3	Computation	177	426	724	62
18	2	4	Visuospatial	169	450	793	24
19	1	1		184	423	996	129
19	1	2		190	424	968	129
19	1	3		194	428	928	148
19	1	4		194	425	941	150
19	2	1	Casual	183	421	919	103
19	2	2	Recall	188	419	934	120
19	2	3	Computation	191	415	1095	58
19	2	4	Visuospatial	179	428	938	72
20	1	1		161	393	848	6
20	1	2		161	375	823	10
20	1	3		159	390	879	3
20	1	4		156	391	727	5
20	2	1	Casual	159	381	634	1
20	2	2	Recall	165	345	601	1
20	2	3	Computation	154	375	667	1
20	2	4	Visuospatial	148	363	1118	1
22	1	1		181	430	1395	129
22	1	2		177	407	1464	117
22	1	3		185	425	1563	94
22	1	4		182	421	1622	83
22	2	1	Casual	184	412	1081	103
22	2	2	Recall	178	416	1110	121
22	2	3	Computation	182	417	1217	120
22	2	4	Visuospatial	183	414	1121	136

Table A1 cont'd. Data Listing of Computed Fixation Means

Participant	Trial Run	Time Block	Question	Express Mean	Modal Mean (ms)	Cognitive Mean	Cognitive Count

				(ms)		(ms)	
23	1	1		200	423	1110	150
23	1	2		207	413	1048	131
23	1	3		204	417	1020	115
23	1	4		217	415	1044	116
23	2	1	Casual	217	410	927	143
23	2	2	Recall	198	419	972	109
23	2	3	Computation	210	415	923	133
23	2	4	Visuospatial	191	412	991	124
24	1	1		160	405	1014	1
24	1	2		157	370	874	2
24	1	3		152	394	742	2
24	1	4		160	550	1003	1
24	2	1	Casual	164	389	782	7
24	2	2	Recall	160	380	727	5
24	2	3	Computation	164	389	782	7
24	2	4	Visuospatial	162	339	618	1
25	1	1		192	421	998	178
25	1	2		184	438	1014	181
25	1	3		193	422	912	161
25	1	4		193	435	942	145
25	2	1	Casual	198	424	900	135
25	2	2	Recall	190	428	953	124
25	2	3	Computation	196	425	1269	113
25	2	4	Visuospatial	184	409	1094	137
26	1	1		210	420	1146	111
26	1	2		208	427	988	115
26	1	3		199	428	972	102
26	1	4		199	428	1157	99
26	2	1	Casual	196	423	884	105
26	2	2	Recall	186	415	849	80
26	2	3	Computation	199	417	896	76
26	2	4	Visuospatial	189	419	981	58
27	1	1		185	411	862	115
27	1	2		184	418	905	100
27	1	3		179	416	858	73
27	1	4		182	417	894	61
27	2	1	Casual	180	403	735	37
27	2	2	Recall	180	399	793	48
27	2	3	Computation	172	405	814	56
27	2	4	Visuospatial	170	417	839	47

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